**PAPER • OPEN ACCESS**

# Development of optimal location and design capacity of wastewater treatment plants for urban areas: a case study in Samawah city

To cite this article: Amjad Hussien *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **671** 012089

IOP Conf. Series: Materials Science and Engineering **671** (2020) 012089 doi:10.1088/1757-899X/671/1/012089

# Development of optimal location and design capacity of wastewater treatment plants for urban areas: a case study in Samawah city

**Amjad Hussien[1,3], Noorance Al-Mukaram[1,3], and Ruqayah Mohammed[2,3]**

[1] Civil Engineering Department, College of Engineering, The University of Al-Muthanna, Samawah, Iraq
[2] Civil Engineering Department, College of Engineering, The University of Babylon, Hilla, Iraq
[3] Civil Engineering Research Group, School of Computing, Science and Engineering, The University of Salford, Newton Building, Peel Park Campus, Salford, Greater Manchester M5 4WT, United Kingdom

Corresponding E-mail: A.hussein3@edu.salford.ac.uk

**Abstract.** Water, and related wastewater structures, are critical factors in the existence and the improvement of civilizations. Wastewater gathering and management has a considerable effect on the climate and economy at both regional and global level, and, accordingly, it is appropriate to advance actions that guarantee effective management for wastewater, particularly in urban areas. This research thus examined the environmental and economic aspects of proposed locations for wastewater treatment plants. Samawah city, located in the southern part of Iraq, was selected as a case study for the research methodology, and for research purposes, the studied city was divided into three main zones (1, 2, and 3) of sixteen areas. The Google Earth tool was used to calculate the lowest elevations in the studied zones in order to assess the suggested positions of treatment plants. Additionally, the WinQSB program was utilised to select the most appropriate positions for treatment plants based on data obtained from local government departments. These data include population, water consumption, and required lengths and subsequent cost of pipes. This research thus developed a new strategy for assigning the locations of wastewater treatment plants.

## 1. Introduction

In general, treatment of wastewater is essential to meet regional and national water standards and policy aims. The focal aim of wastewater treatment plants is to discharge effluent to the surrounding environment with the fewest harmful effects possible, preventing environment pollution by releasing only treated wastewater [1,2]. Wastewater management thus becomes an extremely important issue for city councils, particularly in rural areas where no drainage and sewage systems are provided.

Treatment plants have been established since the 19th century [3,4,5]. However, public health is still negatively affected by untreated sewage and artificial flows polluting rivers, marshes, and land [6,7,8]. As a result, sewage treatment plants have become even more necessary, and enforcement laws have been introduced to reduce pollution and to increase health and environmental safety levels. Environmental analysis and research in recent years has taken both social and physical impacts into consideration during the allocation of treatment plants. More specifically, researchers have studied the environmental effects of treatment plants' location on both humans and other organisms. Other side effects such as odours, noise, and architectural design factors have also been considered in such studies [9,10,11]. Therefore, selection of the best location for wastewater treatment plants must consider many essential aspects with respect to the environment and public health.

The focus of this research is determine the shortest pathway of wastewater to the treatment plant, generating minimum cost. This is achieved by addressing the following targets: (i) selecting the appropriate place for a wastewater treatment plant; (ii) selecting the most effective cost plan among many potential alternatives; and (iii) balancing the required design capacity of the wastewater treatment plant and the governed area. Details of the data collection method and research analysis tools are described in the following sections. Linear goal programming using the WinQSB tool was applied in order to determine the most appropriate location for the treatment plant [12], as this provides mathematical models that are useful in making decisions with regard to engineering research management. This research can thus be applied and used as a helpful guide for engineers planning and designing wastewater treatment plants within urban areas.

## 2. Methodology

### *2.1 Study Area Description*

Samawah is the contemporary capital of the Al-Muthanna Governorate. The city is located midway between Basra and Baghdad at Latitude 31.309 and Longitude 45.280, as shown in figure 1. The map of Iraq used in this study was downloaded from the Global Administrative Areas Database (GADM) [13], which is a spatial database of the world’s administrative areas’ locations for use in geographic information system (GIS). The GADM provides multiple attributes, including the name, address and elevation of each area.

To achieve the main aims of this research, Samawah was chosen for the application of the research methodology. The city was divided into three main zones (1, 2 and 3) featuring 16 areas, as shown in figure 2. Each zone included one treatment plant to serve multiple areas that was located in the minimum elevation of the zone. The zones were identified with aid of the Google Earth tool (GET), a program that renders a three dimensional (3D) representation of the earth from satellite imagery [14].

### *2.2 Data Collection*

The main focus of this research is the disposal of wastewater, with this being moved from the populated areas to the treatment plant before extrusion into the Euphrates River.

The population figures considered in this study were based on data from the Samawah Census Office. The treatment plants (1, 2, and 3) were then located at the minimum elevations in each of the three city zones, as illustrated in figure 2. The elevations of the 16 areas were obtained using the Google Earth tool [14].

Sewage was deemed to stream from higher to lower levels in each area by means of pipelines with 1,200 mm diameters. The cost of one metre of pipeline is thus assessed as US$175 at local market prices. The average daily water consumption per capita was estimated to be 0.25 $m^3$. Hence, the average daily sewage flow was obtained by multiplying the number of people living in the area by the daily water consumption per capita [9]. Finally, the maximum design capacity of each treatment plant (45,360 $m^3$ per day) was assigned by the Al-Muthanna Sewage Department.

Table 1 summarises the studied areas with their corresponding elevations, major pipe details including length and cost, population, and water consumption per day.

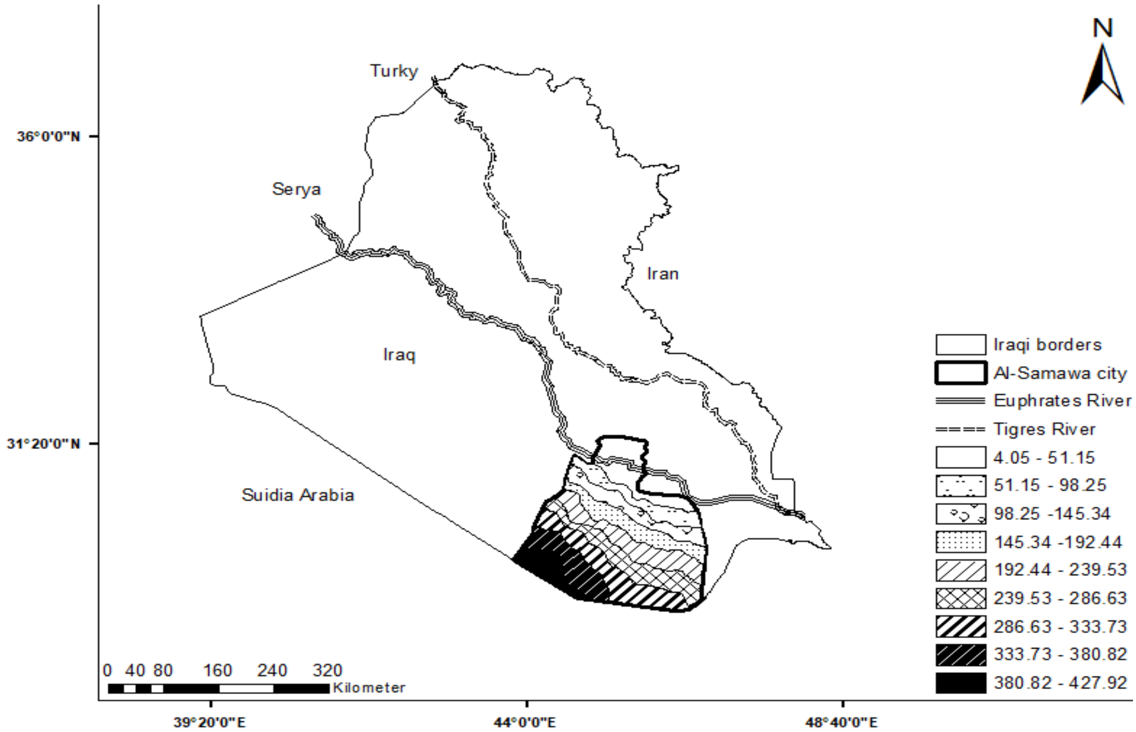


**Figure 1.** Location of the studied city with the corresponding elevations.

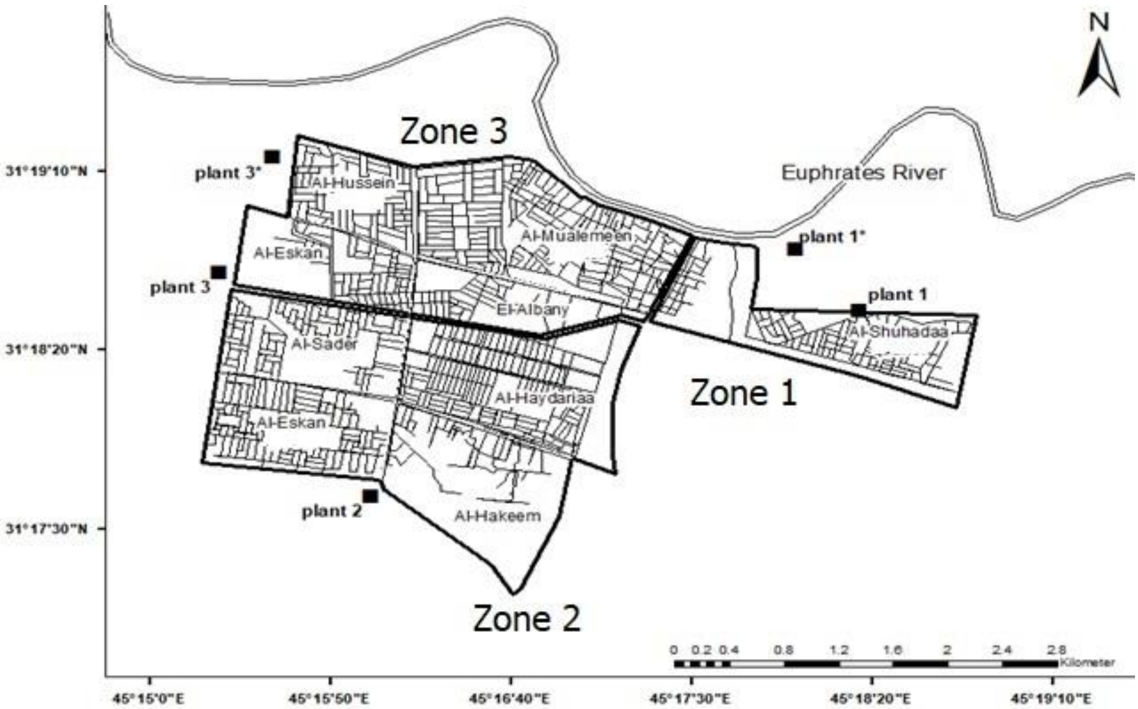


**Figure 2.** The selected zones (1, 2 and 3) with the corresponding areas and the wastewater treatment plant locations in Samawah.

**Table 1.** Samawah areas involved in this study. including elevation above the sea level, lengths and cost of pipes, population, and water consumption.

| City zone | Area | Elevation (m) | Length of major pipe[a] (m) | Cost of major pipe[a] (USD) | Number of population[b] | Water consumption[a] ($m^3$ per day) |
|---|---|---|---|---|---|---|
| 1 | Al-Shuhada | 17.38 | 192 | 33,600 | 15,308 | 3,827 |
| 1 | Al-Sharqi | 17.68 | 947 | 165,725 | 11,800 | 2,950 |
| 2 | 270 Dar | 11.28 | 150 | 26,250 | 17,140 | 4,285 |
| 2 | Al-Hakeem | 12.20 | 1,231 | 215,425 | 26,468 | 6,617 |
| 2 | Al-Askari | 13.11 | 802 | 140,350 | 19,350 | 4,837 |
| 2 | Al-Jumhori | 13.72 | 50 | 8,750 | 23,752 | 5,938 |
| 2 | Al-Sader | 14.02 | 1,604 | 280,700 | 13,974 | 3,493 |
| 2 | Al-Haydaria | 14.33 | 100 | 17,500 | 23,350 | 5,882 |
| 2 | Al-Shurtah | 14.63 | 75 | 13,125 | 23,794 | 5,948 |
| 3 | Al-Hussain | 12.50 | 1,550 | 271,250 | 29,350 | 7,337 |
| 3 | Al-Eskan | 12.80 | 200 | 35,000 | 23,794 | 5,993 |
| 3 | Al-Bani | 13.11 | 1,400 | 245,000 | 17,530 | 4,382 |
| 3 | Al-Jaddan | 13.41 | 100 | 175,000 | 17,538 | 4,384 |
| 3 | Al-Mualmeen | 14.02 | 700 | 122,500 | 23,752 | 5,938 |
| 3 | Al-Dhubat | 14.94 | 150 | 26,250 | 21,384 | 5,346 |
| 3 | Al-Gharbi | 15.55 | 1,500 | 262,500 | 19,796 | 4,949 |
| Total | | | 10,751 | 2,038,925 | 328,080 | 82,106 |

[a] Data were obtained from Al-Muthanna Sewage Department.

[b] Data were obtained from Samawah Census Office.

*2.3 The Goal Programming Model*

The WinQSB Program utilises Linear Goal Programming (GP) and Integer Linear Goal Programming (IGP) [15,16,17,18,19]. GP and IGP models involve one or more linear goals (objective functions) and a limited number of linear constraints. Decision variables may also be bounded with specific values. All decision variables are considered to be continuous numbers [20,21,22]. The general equation of minimisation linear goal programming thus follows the formula [23]

$$Minimise\ Z\ =\ \left(\sum_{j=1}^{n} C_{ij}\, X_j +\ \cdots\ + C_{in}\, X_n\right) +\ n_i - p_i\ = b_i \qquad (Goal\ level\ i) \tag{1}$$

where $Z$ is the objective function, $X_j$ is a variable, $C_{ij}$ is the coefficient of variable, $b_i$ is the level of priority of goal $i$, $n_i$ is the degree of the minimum achievement of goal, and $p_i$ is the degree of the maximum achievement of goal. Since $p_i$ and $n_i$ cannot be added together, one or both of them must equal zero [24]. Hence, $p_i \times n_i = 0$.

To solve this problem here, the variable ($X_{ijk}$) was defined as the quantity of sewage from area $i$ sent to treatment plant $j$ in city zone $k$.

The final equation was formulated according to the goals prepared by the Al-Muthanna Sewage Office, using the collected data shown in table 1 with reference to the suggested locations of treatment plants. The collected data were input into the program to achieve the goals as follows:

*2.3.1 Goal One*

This had 16 constraints, each of which represented the quantity of sewage (m$^3$ per day) from each area to be disposed of to treatment plants, as shown in the following equations set from (*a*) to (*p*):

$$\left.\begin{cases} X_{111} + n_1 - p_1 = 3{,}827 & (a) \\ X_{211} + n_2 - p_2 = 2{,}950 & (b) \\ X_{122} + n_3 - p_3 = 4{,}285 & (c) \\ X_{222} + n_4 - p_4 = 6{,}617 & (d) \\ X_{322} + n_5 - p_5 = 4{,}837 & (e) \\ X_{422} + n_6 - p_6 = 5{,}938 & (f) \\ X_{522} + n_7 - p_7 = 3{,}493 & (g) \\ X_{622} + n_8 - p_8 = 5{,}882 & (h) \\ X_{722} + n_9 - p_9 = 5{,}948 & (i) \\ X_{133} + n_{10} - p_{10} = 7{,}337 & (j) \\ X_{233} + n_{11} - p_{11} = 5{,}993 & (k) \\ X_{333} + n_{12} - p_{12} = 4{,}382 & (l) \\ X_{433} + n_{13} - p_{13} = 4{,}384 & (m) \\ X_{533} + n_{14} - p_{14} = 5{,}938 & (n) \\ X_{633} + n_{15} - p_{15} = 5{,}346 & (o) \\ X_{733} + n_{16} - p_{16} = 4{,}949 & (p) \end{cases}\right\} \quad \textit{Goal (1)}$$

*2.3.2 Goal Two*

This included three constraints on the proposed plants in order to achieve the maximum design capacity of 45,360 m$^3$ per day. Sewage collected from the studied areas and disposed of into the treatment plants at each zone was thus presented in the following set of equations from (*a*) to (*c*):

$$\left.\begin{cases} X_{111} + X_{211} + n_{17} - p_{17} = 45{,}360 & (a) \\ X_{122} + X_{222} + X_{322} + X_{422} + X_{522} + X_{622} + X_{722} + n_{18} - p_{18} = 45{,}360 & (b) \\ X_{133} + X_{233} + X_{333} + X_{433} + X_{533} + X_{633} + X_{733} + n_{19} - p_{19} = 45{,}360 & (c) \end{cases}\right\} \quad \textit{Goal (2)}$$

*2.3.3 Goal Three*

This included three constraints representing the shortest sewage disposal network from the served areas to the treatment plants at each zone, as illustrated in equations from (*a*) to (*c*):

$$\left.\begin{cases} 192\, X_{111} + 947\, X_{211} + n_{20} - p_{20} = 0 & (a) \\ 150\, X_{122} + 1{,}231\, X_{222} + 802\, X_{322} + 50\, X_{422} + \\ 1{,}604\, X_{522} + 100\, X_{622} + 75\, X_{722} + n_{21} - p_{21} = 0 & (b) \\ 1{,}550\, X_{133} + 200\, X_{233} + 1{,}400\, X_{333} + 100\, X_{433} + \\ 700\, X_{533} + 150\, X_{633} + 1{,}500\, X_{733} + n_{22} - p_{22} = 0 & (c) \end{cases}\right\} \quad \textit{Goal (3)}$$

*2.3.4 Goal Four*

This had a single constraint representing the cost of sewage disposal from the corresponding areas into the treatment plants, as shown in the following equation:

$$\left.\begin{cases} 33{,}600\, X_{111} + 165{,}725\, X_{211} + 26{,}250\, X_{122} + 215{,}425\, X_{222} + 140{,}350\, X_{322} + \\ 8{,}750\, X_{422} + 280{,}700\, X_{522} + 17{,}500\, X_{622} + 13{,}125\, X_{722} + 27{,}125\, X_{133} + \\ 35{,}000\, X_{233} + 245{,}000\, X_{333} + 17{,}500\, X_{433} + 122{,}500\, X_{533} + 26{,}250\, X_{633} + \\ 262{,}500\, X_{733} + n_{23} + p_{23} = 0 \end{cases}\right\} \quad \textit{Goal (4)}$$

## 3. Solutions, Results, and Discussion

The optimum solution program was applied in order to select the best locations for the sewage treatment plants taking into consideration the outlined environmental engineering requirements. The results of the statistical and engineering analysis were based on two main considerations, the first being to select the most appropriate location for the treatment plant, and the second being to select the most economical solution from among several potential alternatives.

It was found that the locations of the sewage treatment plants near populated areas required more than one solution to be generated to determine suitable positions for these plants. It was thus necessary to determine the optimum solution based on the outputs of the WinQSB program. A brief description of these solutions is presented in the next sections.

### *3.1 First Solution*

In order to achieve the goals outlined, the input data of suggested plants 1, 2, and 3 (see figure 2) were considered. After running the program, results were obtained as presented in table 2.

**Table 2.** Results for the 1st solution for treatment plants 1, 2 and 3.

| Variable $X_{ijk}$ | Value | Variable $n_i$ | Value | Variable $p_i$ | Value |
|---|---|---|---|---|---|
| $X_{111}$ | 42,410 | $n_1$ | 0 | $p_1$ | 38,583 |
| $X_{211}$ | 2,950 | $n_2$ | 0 | $p_2$ | 0 |
| $X_{122}$ | 4,285 | $n_3$ | 0 | $p_3$ | 0 |
| $X_{222}$ | 6,617 | $n_4$ | 0 | $p_4$ | 0 |
| $X_{322}$ | 4,837 | $n_5$ | 0 | $p_5$ | 0 |
| $X_{422}$ | 5,938 | $n_6$ | 0 | $p_6$ | 0 |
| $X_{522}$ | 3,493 | $n_7$ | 0 | $p_7$ | 0 |
| $X_{622}$ | 5,882 | $n_8$ | 0 | $p_8$ | 0 |
| $X_{722}$ | 5,948 | $n_9$ | 0 | $p_9$ | 0 |
| $X_{133}$ | 7,337 | $n_{10}$ | 0 | $p_{10}$ | 0 |
| $X_{233}$ | 5,993 | $n_{11}$ | 0 | $p_{11}$ | 0 |
| $X_{333}$ | 4,382 | $n_{12}$ | 0 | $p_{12}$ | 0 |
| $X_{433}$ | 4,384 | $n_{13}$ | 0 | $p_{13}$ | 0 |
| $X_{533}$ | 5,938 | $n_{14}$ | 0 | $p_{14}$ | 0 |
| $X_{633}$ | 5,346 | $n_{15}$ | 0 | $p_{15}$ | 0 |
| $X_{733}$ | 4,949 | $n_{16}$ | 0 | $p_{16}$ | 0 |
| | | $n_{17}$ | 0 | $p_{17}$ | 0 |
| | | $n_{18}$ | 8,360 | $p_{18}$ | 0 |
| | | $n_{19}$ | 7,031 | $p_{19}$ | 0 |
| | | $n_{20}$ | 0 | $p_{20}$ | 10,936,370 |
| | | $n_{21}$ | 0 | $p_{21}$ | 19,601,524 |
| | | $n_{22}$ | 0 | $p_{22}$ | 31,526,150 |
| | | $n_{23}$ | 0 | $p_{23}$ | 10,861,207,552 |

Goal one: The obtained value is zero. This represents the total quantity of sewage taken from all areas and disposed into the treatment plants in each city zone.

Goal two: After running the program, the resulting value was 15,391 $m^3$ per day. In fact, this value obtained from the WinQSB program was related to the items of this goal ($n_{18} + n_{19} = 8,360 + 7,031 =$

15,391). The three treatment plants could thus possibly have larger design capacities later. The value of 15,391 $m^3$ per day represents the additional quantity of sewage flow that should be considered in the design capacity of the treatment plants in the future.

Goal three: Its value is 62,064,044 m.$m^3$ per day. This value is obtained from running the WinQSB program related to the items of this goal ($p_{20}$ + $p_{21}$ + $p_{22}$ = 10,936,370 + 19,601,524 + 31,526,150 = 62,064,044). The value of 62,064,044 is obtained by multiplying of the total length of pipeline by the quantity of sewage flow, about 15,391 $m^3$ per day, in the future. Therefore, the length of the pipelines used to dispose of the sewage can be obtained by dividing this value by the quantity of sewage flow. The result is 4,032 m which represents the possible length of pipelines that should be considered in the design capacity of the three treatment plants in the future.

Goal four: The suggested value is 10,861,207,552 \$.$m^3$ per day. This was obtained from the WinQSB program in relation to the items of this goal ($p_{23}$ = 10,861,207,552). The value of 10,861,207,552 is equal to the cost of sewage disposal of about 15,391 $m^3$ per day in the future. Therefore, the cost to dispose the sewage can be obtained by dividing the mentioned value by the quantity of sewage flow. The resulting figure, US\$705,685 should thus be considered in the design capacity of those three treatment plants as well as sewage networks in the future.

### *3.2 Second Solution*

In this solution, the input data of proposed plants 1*, 2, and 3 were considered. Treatment plant 1 was moved to a new location, 1*, while other plants, 2 and 3, were fixed as illustrated in figure 2. Subsequently, the cost and lengths of the pipelines connected to those plants varied. The new statements were input as items and the WinQSB program re-run to obtain results as shown in table 3.

Goal one: The obtained value was zero. This represents the total quantities of sewage taken from the areas and disposed of into the treatment plants of the city zones.

Goal two: After running the program, the resulting value was 15,391 $m^3$ per day. This value is related to the items of this goal ($n_{18}$ + $n_{19}$ = 8,360 + 7,031 = 15,391).

Goal three: This value was 74,070,708 m.$m^3$ per day. This value is obtained from the items of this goal ($p_{20}$ + $p_{21}$ + $p_{22}$ = 22,943,056 + 19,601,524 + 31,526,150 = 74,070,730). The value of 74,070,730 results from multiplying of the total length of pipeline by the quantity of sewage flow, which is about 15,391 $m^3$ per day. Therefore, the length of the pipelines used to dispose of sewage can be obtained by dividing the value of ($p_{20}$ + $p_{21}$ + $p_{22}$) by the quantity of sewage flow. The result, 4,812 m, represents the possible length of pipeline that should be considered in the design capacity of the three treatment plants in the future.

Goal four: This value is 12,962,377,728 \$.$m^3$ per day, obtained from the items of this goal ($p_{23}$ = 12,962,377,728). The value of 12,962,377,728 is equal to the cost of sewage disposal of about 15,391 $m^3$ per day in the future. Therefore, the cost of disposing of the sewage can be obtained by dividing the mentioned value by the quantity of sewage flow. The result is US\$842,205, which should be considered as part of the design capacity of the three treatment plants and sewage network in the future.

**Table 3.** The results for the 2nd solution for treatment plants 1*, 2 and 3.

| Variable $X_{ijk}$ | Value | Variable $n_i$ | Value | Variable $p_i$ | Value |
|---|---|---|---|---|---|
| $X_{111}$ | 3,827 | $n_1$ | 0 | $p_1$ | 0 |
| $X_{211}$ | 41,533 | $n_2$ | 0 | $p_2$ | 38,583 |
| $X_{122}$ | 4,285 | $n_3$ | 0 | $p_3$ | 0 |
| $X_{222}$ | 6,617 | $n_4$ | 0 | $p_4$ | 0 |
| $X_{322}$ | 4,837 | $n_5$ | 0 | $p_5$ | 0 |
| $X_{422}$ | 5,938 | $n_6$ | 0 | $p_6$ | 0 |
| $X_{522}$ | 3,493 | $n_7$ | 0 | $p_7$ | 0 |
| $X_{622}$ | 5,882 | $n_8$ | 0 | $p_8$ | 0 |
| $X_{722}$ | 5,948 | $n_9$ | 0 | $p_9$ | 0 |
| $X_{133}$ | 7,337 | $n_{10}$ | 0 | $p_{10}$ | 0 |
| $X_{233}$ | 5,993 | $n_{11}$ | 0 | $p_{11}$ | 0 |
| $X_{333}$ | 4,382 | $n_{12}$ | 0 | $p_{12}$ | 0 |
| $X_{433}$ | 4,384 | $n_{13}$ | 0 | $p_{13}$ | 0 |
| $X_{533}$ | 5,938 | $n_{14}$ | 0 | $p_{14}$ | 0 |
| $X_{633}$ | 5,346 | $n_{15}$ | 0 | $p_{15}$ | 0 |
| $X_{733}$ | 4,949 | $n_{16}$ | 0 | $p_{16}$ | 0 |
| | | $n_{17}$ | 0 | $p_{17}$ | 0 |
| | | $n_{18}$ | 8,360 | $p_{18}$ | 0 |
| | | $n_{19}$ | 7,031 | $p_{19}$ | 0 |
| | | $n_{20}$ | 0 | $p_{20}$ | 22,943,056 |
| | | $n_{21}$ | 0 | $p_{21}$ | 19,601,524 |
| | | $n_{22}$ | 0 | $p_{22}$ | 31,526,150 |
| | | $n_{23}$ | 0 | $p_{23}$ | 12,962,377,728 |

### *3.3 Third Solution*

In this solution, the input data for suggested plants 1, 2 and 3* were considered. Treatment plant 3 was moved to a new location, 3*, while other plants 1 and 2 were fixed, as shown in figure 2. Subsequently, the cost and lengths of the pipelines connected to those plants varied. Similarly, new statements were input as items and the WinQSB program re-run to obtain results as presented in table 4.

Goal one: the given value is zero. This represents the total quantities of sewage taken from the areas and disposed of to the treatment plants in the city zones.

Goal two: The obtained value was 15,391 $m^3$ per day. This value is related to the items of this goal ($n_{18} + n_{19}$ = 8360 + 7,031 = 15,391).

Goal three: The value was 65,844,328m.$m^3$ per day, obtained from ($p_{20} + p_{21} + p_{22}$ = 10,936,370 + 23,381,810 + 31,526,150= 65,844,330). The 65,844,330 figure is the result of multiplying the total length of pipeline by the quantity of sewage flow, which is about 15,391 $m^3$ per day. Therefore, the length of the pipelines used to dispose of the sewage can be obtained by dividing the value of ($p_{20} + p_{21} + p_{22}$) by the quantity of sewage flow. The result is 4,278 m, which represents the possible length of pipelines that should be included in the design capacity of the three treatment plants in the future.

Goal four: This value is 11,522,757,632 \$.$m^3$ per day, obtained from the items of this goal ($p_{23}$ = 11,522,757,632). Fundamentally, the value of 11,522,757,632 is equal to the cost of sewage disposal of about 15,391 $m^3$ per day in the future. Therefore, the cost of disposing of the sewage can be obtained by dividing the value of $p_{23}$ by the quantity of sewage flow. The result is US$748,668, which should be considered in the design capacity of treatment plants and sewage networks in the future.

**Table 4.** Results of the 3rd solution for treatment plants 1, 2 and 3*.

| Variable $X_{ijk}$ | Value | Variable $n_i$ | Value | Variable $p_i$ | Value |
|---|---|---|---|---|---|
| $X_{111}$ | 42,410 | $n_1$ | 0 | $p_1$ | 38,583 |
| $X_{211}$ | 2,950 | $n_2$ | 0 | $p_2$ | 0 |
| $X_{122}$ | 4,285 | $n_3$ | 0 | $p_3$ | 0 |
| $X_{222}$ | 6,617 | $n_4$ | 0 | $p_4$ | 0 |
| $X_{322}$ | 4,837 | $n_5$ | 0 | $p_5$ | 0 |
| $X_{422}$ | 5,938 | $n_6$ | 0 | $p_6$ | 0 |
| $X_{522}$ | 3,493 | $n_7$ | 0 | $p_7$ | 0 |
| $X_{622}$ | 5,882 | $n_8$ | 0 | $p_8$ | 0 |
| $X_{722}$ | 5,948 | $n_9$ | 0 | $p_9$ | 0 |
| $X_{133}$ | 7,337 | $n_{10}$ | 0 | $p_{10}$ | 0 |
| $X_{233}$ | 5,993 | $n_{11}$ | 0 | $p_{11}$ | 0 |
| $X_{333}$ | 4,382 | $n_{12}$ | 0 | $p_{12}$ | 0 |
| $X_{433}$ | 4,384 | $n_{13}$ | 0 | $p_{13}$ | 0 |
| $X_{533}$ | 5,938 | $n_{14}$ | 0 | $p_{14}$ | 0 |
| $X_{633}$ | 5,346 | $n_{15}$ | 0 | $p_{15}$ | 0 |
| $X_{733}$ | 4,949 | $n_{16}$ | 0 | $p_{16}$ | 0 |
| | | $n_{17}$ | 0 | $p_{17}$ | 0 |
| | | $n_{18}$ | 8,360 | $p_{18}$ | 0 |
| | | $n_{19}$ | 7,031 | $p_{19}$ | 0 |
| | | $n_{20}$ | 0 | $p_{20}$ | 10,936,370 |
| | | $n_{21}$ | 0 | $p_{21}$ | 23,381,810 |
| | | $n_{22}$ | 0 | $p_{22}$ | 31,526,150 |
| | | $n_{23}$ | 0 | $p_{23}$ | 11,522,757,632 |

### *3.4 Fourth Solution*

In this solution, the input data for proposed plants 1*, 2 and 3* were considered. Treatment plants 1 and 3 were moved to alternative locations 1* and 3* (see figure 2) while plant 2 was fixed. Subsequently, the cost and lengths of the pipelines connected to those plants varied. The new statements were input as items and the WinQSB program re-run in order to obtain results as given in table 5.

Goal one: the obtained value is zero. This value represents the total quantities of sewage taken from the areas and disposed of to the treatment plants of the city zones.

Goal two: The resulting value is 15,391 m$^3$ per day, obtained in relation to the items of this goal ($n_{18} + n_{19}$ = 8,360 + 7,031 = 15,361).

Goal three: This value is 77,851,016 m.m$^3$/day, related to the items of this goal ($p_{20} + p_{21} + p_{22}$ = 22,943,056 + 23,381,810 + 31,526,150 = 77,851,016). The value of 77,851,016 results from multiplying the total length of pipeline by the quantity of sewage flow, which is about 15,391 m$^3$ per day in the future. Therefore, the length of the pipelines used to dispose of the sewage can be obtained by dividing the value above by the quantity of sewage flow. The result is 5,058 m, which represents the possible length of pipelines that should be included in the design capacity of the three treatment plants in the future.

Goal four: This value is 13,623,927,808 \$.m$^3$per day, found in relation to the items of this goal ($p_{23}$ = 13,623,927,808). Accordingly, the value of 13,623,927,808 is equal to the cost of sewage disposal of about 15,391 m$^3$ per day. Therefore, the cost of disposing of the sewage can be obtained by dividing the value of $p_{23}$ by the quantity of sewage flow. The result is US\$885,188, which should be considered in the calculation of design capacity of treatment plants and sewage network in the future.

**Table 5.** Results of the 4th solution for treatment plants 1*, 2 and 3*.

| Variable $X_{ijk}$ | Value | Variable $n_i$ | Value | Variable $p_i$ | Value |
|---|---|---|---|---|---|
| $X_{111}$ | 3,827 | $n_1$ | 0 | $p_1$ | 0 |
| $X_{211}$ | 41,533 | $n_2$ | 0 | $p_2$ | 38,583 |
| $X_{122}$ | 4,285 | $n_3$ | 0 | $p_3$ | 0 |
| $X_{222}$ | 6,617 | $n_4$ | 0 | $p_4$ | 0 |
| $X_{322}$ | 4,837 | $n_5$ | 0 | $p_5$ | 0 |
| $X_{422}$ | 5,938 | $n_6$ | 0 | $p_6$ | 0 |
| $X_{522}$ | 3,493 | $n_7$ | 0 | $p_7$ | 0 |
| $X_{622}$ | 5,882 | $n_8$ | 0 | $p_8$ | 0 |
| $X_{722}$ | 5,948 | $n_9$ | 0 | $p_9$ | 0 |
| $X_{133}$ | 7,337 | $n_{10}$ | 0 | $p_{10}$ | 0 |
| $X_{233}$ | 5,993 | $n_{11}$ | 0 | $p_{11}$ | 0 |
| $X_{333}$ | 4,382 | $n_{12}$ | 0 | $p_{12}$ | 0 |
| $X_{433}$ | 4,384 | $n_{13}$ | 0 | $p_{13}$ | 0 |
| $X_{533}$ | 5,938 | $n_{14}$ | 0 | $p_{14}$ | 0 |
| $X_{633}$ | 5,346 | $n_{15}$ | 0 | $p_{15}$ | 0 |
| $X_{733}$ | 4,949 | $n_{16}$ | 0 | $p_{16}$ | 0 |
| | | $n_{17}$ | 0 | $p_{17}$ | 0 |
| | | $n_{18}$ | 8,360 | $p_{18}$ | 0 |
| | | $n_{19}$ | 7,031 | $p_{19}$ | 0 |
| | | $n_{20}$ | 0 | $p_{20}$ | 22,943,056 |
| | | $n_{21}$ | 0 | $p_{21}$ | 23,381,810 |
| | | $n_{22}$ | 0 | $p_{22}$ | 31,526,150 |
| | | $n_{23}$ | 0 | $p_{23}$ | 13,623,927,808 |

## 4. Conclusions and Recommendations for Future Research

Based on the outputs of the WinQSB program, the best solution to assigning the locations of treatment plants is the fourth solution. This, however, suggests that the sewage treatment plants might need longer pipeline lengths (approximately 5,058 m) and increased costs (approximately US$885,188) in order to take expansion of the sewage network in the future into account.

Despite the fact that sewage projects and treatment plants have with high costs, they have multiple positive effects on the national economy and environmental safety. Purification techniques may reduce the risk of several diseases. However, these projects do have other implications for the environment, and more attention should be paid to these. In addition, wastewater treatment plants require good maintenance, management, and good engineering staff in order to achieve the best performance, adding to their ongoing costs.

## 5. Acknowledgements

The authors acknowledge the support of their respective institutions. Deep gratitude and sincere thanks are offered to Al-Muthanna Sewage Department and Samawa Census Office for providing the required data. This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

## 6. References

[1] Reid R N 2003. *Water Quality Systems: Guide for Facility Managers*. CRC Press.

[2] Boguniewicz-Zablocka J , Klosok-Bazan I , Capodaglio A and Ploskonka J 2018. *Planning the optimal solution for wastewater management in rural areas - case study*. MATEC Web of Conferences, 174, p.01035

[3] Gilcreas, F.W., 1966. Standard methods for the examination of water and waste water. *American Journal of Public Health and the Nations Health*, 56(3), pp.387-388.

[4] Asano T 2002. Water from (waste) water–the dependable water resource. The 2001 Stockholm Water Prize Laureate Lecture. *Water science and technology*, 45(8), pp.23-33.

[5] Al-Isawi, R.H., 2016. *Urban wastewater treatment with mature constructed wetlands*. PhD thesis, University of Salford, School of Computing, Science and Engineering.

[6] Hussein, A., 2017. *Azo textile dyes wastewater treatment with constructed wetlands: design and operation of experimental vertical-flow constructed wetlands applied for the treatment of azo textile dyes (with/without artificial wastewater)*. PhD thesis, University of Salford, School of Computing, Science and Engineering.

[7] Hussein, A. and Scholz, M. 2017. Dye wastewater treatment by vertical-flow constructed wetlands. *Ecological Engineering*. 101, 28-38.

[8] Hussein, A. and Scholz, M. 2017. Treatment of artificial wastewater containing two azo textile dyes by vertical-flow constructed wetlands. *Environmental Science and Pollution Research*. pp.1-20.

[9] McGhee, T.J. and Steel, E.W., 1991. *Water supply and sewerage*. Vol. 6. New York: McGraw-Hill.

[10] Viessman, W., Hammer, M. J., Perez, E. M., & Chadik, P. A. (2009). *Water supply and pollution control*. New Jersey: Pearson Prentice Hall.

[11] Davis, M. L. 2010. *Water and wastewater engineering*. McGraw-Hill.

[12] WinQSB 2018. Quantitative System for Business. Retrieved from: https://winqsb.secursoft.net/download. [Accessed 4 October 2018].

[13] Global Administrative Areas Database (GADM) 2012. [online]. Available from http://www.gadm.org. [Accessed 11 June 2018].

[14] Google Earth Tool (GET) 2018. [online]. Available from: https://www.google.com/earth/download/gep/agree.html. [Accessed 4 October 2018].

[15] Ozcan, Y.A., 2005. *Quantitative methods in health care management: techniques and applications* 4. John Wiley & Sons.

[16] Liner, B., 2009. *Goal programming for sustainability in total water management.* PhD thesis.

[17] Sharma, J.K., 2010. *Quantitative Methods: Theory and applications*. MacMillan.
[18] Bucur, A., 2012. Examples of using the SPSS and WinQSB softwares for collecting and analyzing data in order to obtain the optimum quality. *Metalurgia International*, 17(6), p.187.
[19] Kumar, K.S. and Babu, A.S., 2012. An integrated method using AHP, DEA and GP for evaluating supply sources. *International Journal of Services and Operations Management*, 11(2), pp.123-150.
[20] Arthur, J.L. and Ravindran, A., 1980. A branch and bound algorithm with constraint partitioning for integer goal programming problems. *European Journal of Operational Research*, 4(6), pp.421-425.
[21] Chang, Y.L. and Desai, K., 2003. *WinQSB*. John Wiley & Sons, Inc.
[22] Sarker, R.A. and Newton, C.S., 2007. *Optimization modelling: a practical approach*. CRC Press.
[23] Bala, K. and Cook, W.D., 2003. Performance measurement with classification information: an enhanced additive DEA model. *Omega*, 31(6), pp.439-450.
[24] Mirrazavi, S.K., Jones, D.F. and Tamiz, M., 2001. A comparison of genetic and conventional methods for the solution of integer goal programmes. *European Journal of Operational Research*, 132(3), pp.594-602.